



AI in Multidisciplinary Engineering: A Holistic Review of Technologies and Trends

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Abstract

Artificial Intelligence (AI) has evolved from a computational tool into a transformative force reshaping every branch of engineering. This review paper explores the depth and breadth of AI integration across major engineering disciplines—including Mechanical, Electrical, Electronics, Computer Science, Civil, Chemical, Aerospace, Biomedical, and Industrial Engineering. By analysing recent advances in machine learning, deep learning, computer vision, natural language processing, and intelligent automation, the paper highlights how AI enhances design optimization, predictive maintenance, smart manufacturing, structural health monitoring, energy management, autonomous systems, process control, and human-machine collaboration. The study also examines domain-specific applications such as digital twins, Industry 4.0, AI-driven materials discovery, intelligent transportation, personalized healthcare systems, and sustainable infrastructure development. Furthermore, the paper discusses emerging challenges involving data quality, interoperability, ethics, and the need for interdisciplinary skill development. This comprehensive review demonstrates that AI is not merely an add-on technology but a foundational enabler driving innovation, efficiency, and intelligent decision-making across all engineering fields, shaping the future of global technological advancement.

1. Introduction

The rapid evolution of Artificial Intelligence (AI) has fundamentally redefined engineering practices across the world. What began as rule-based computational algorithms has matured into intelligent, autonomous, and adaptive systems

capable of perception, reasoning, decision-making, and optimization. Engineering—traditionally dependent on physical experiments, mathematical modelling, and human expertise—now leverages AI to accelerate design cycles,

enhance reliability, reduce operational costs, and enable entirely new capabilities. Today, smart factories optimize themselves, bridges alert engineers before structural failure, aircraft diagnose faults mid-flight, materials are discovered autonomously, and biomedical devices tailor treatments to individual patients. These advancements demonstrate the transformation of classical engineering workflows into data-driven, intelligent ecosystems. This paper provides a comprehensive review of AI's integration into diverse engineering branches and discusses the technologies, challenges, and future directions shaping the next phase of multidisciplinary engineering.

1.1. AI Pipeline in Engineering

AI Pipeline consists of the following structure:

Data Sources → Data Pre-processing → ML/DL Models → Decision Engine → Deployment (Edge/Cloud)

Fig. 1. and Fig. 2. visually explains the full workflow—from sensors to insights—exactly how AI is used in real engineering environments. This is a clear, professional, and complete use case diagram of an AI Pipeline in Engineering, specifically showcasing Predictive Maintenance in Manufacturing. In this context, Data Collection consists of Vibration sensors, Thermal sensors, Acoustic signals and Operational machine data. Data Processing consists of Pre-processing, Noise removal, Feature extraction and Data labelling. Model Training consists of Machine Learning algorithms, Deep neural networks and On-edge or cloud-based training. Deployment consists of Inferring on industrial robots and machines and Integrated with PLC/SCADA systems. Prediction & Insights comprises of Predictive maintenance alerts, Remaining useful life (RUL) estimation, Anomaly detection, Dashboard for engineers [1, 2].

1.2. Digital Twin Architecture

Physical Asset ↔ Sensors ↔ Data Platform ↔ AI/ML Engine ↔ Simulation/Prediction ↔ Control Commands. A Professional Digital Twin Architecture diagram as shown in Fig. 3 comprises of: Physical Asset, Sensors & IoT Layer, Data Acquisition System, Edge/Cloud Processing, AI/ML Model Layer, Simulation Engine, Control & Feedback Loop, Visualization Dashboard. A well-designed Digital Twin Architecture not only

mirrors the physical asset but also enables real-time intelligence by continuously integrating multisource data, simulation models, and AI-driven analytics. Its layered structure ensures that raw sensor data captured from the physical environment is transformed into actionable insights through cloud or edge-based processing pipelines. By combining physics-based models with machine learning predictions, the digital twin can forecast system behavior, optimize operations, and diagnose anomalies before they escalate into failures. The closed-loop feedback mechanism allows the system to automatically adjust operational parameters or assist engineers in decision-making, thus increasing reliability, reducing downtime, and enabling predictive maintenance [3, 4]. As industries adopt Industry 4.0 principles, digital twins serve as the foundational framework for smart factories, autonomous systems, and cyber-physical ecosystems—empowering engineers to test, validate, and optimize processes virtually before implementing them in the real world [5]. Figure 1 shows The Schematic Structure of AI pipeline in Engineering

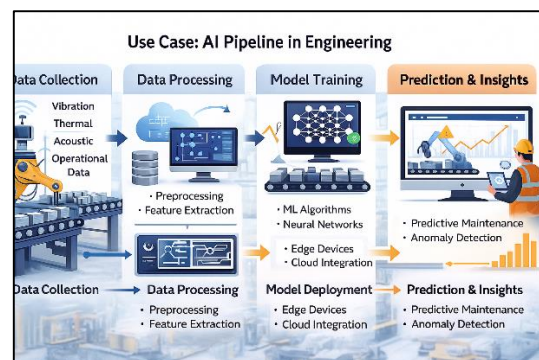


Figure 1 The Schematic Structure of AI pipeline in Engineering

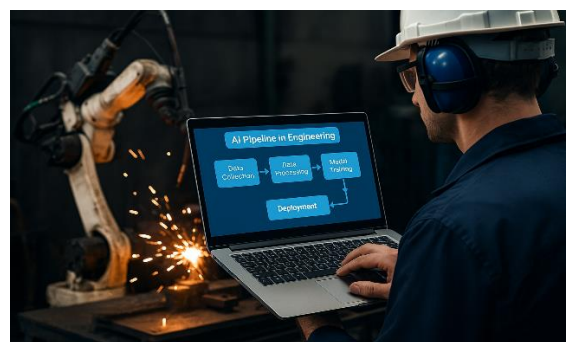


Figure 2 The structure of AI pipeline in Engineering

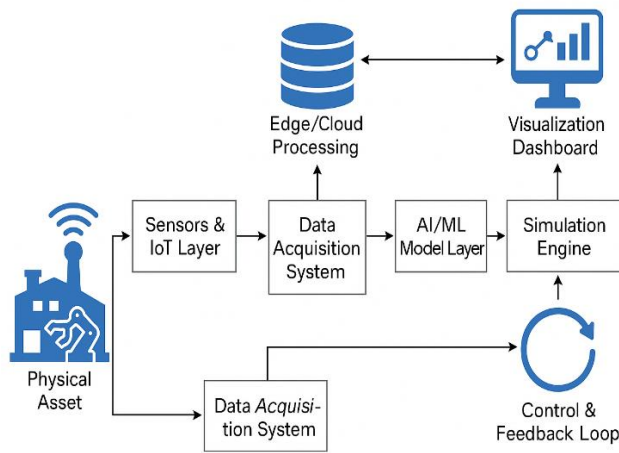


Figure 3 Digital Twin Architecture

1.3. Evolution of AI in Engineering

AI's role in engineering can be understood through three major waves:

- Rule-Based and Expert Systems (1980s–1990s): Early AI supported troubleshooting, diagnostics, and process control through human-designed rules.
- Machine Learning and Data-Driven Modelling (2000s–2010s): Supervised and unsupervised learning allowed systems to learn patterns from sensor data, enabling predictive analytics, intelligent monitoring, and anomaly detection.
- Deep Learning and Autonomous Systems (2015–Present): Advances in computation, big data, and neural networks have enabled computer vision, NLP, robotics, and real-time decision systems, driving full-scale engineering automation.

2. Methodology

2.1. AI Methods and Techniques Used in Engineering

- Machine Learning (ML): Regression, SVMs, random forests, and gradient boosting enable forecasting, classification, and optimization.
- Deep Learning (DL): CNNs, RNNs, LSTMs, and Transformers empower image recognition, signal modelling, and language understanding.
- Computer Vision (CV): Used for defect detection, surveillance, structural monitoring, robotic vision, and medical imaging.

- Natural Language Processing (NLP): Automates documentation, maintenance logs, risk analysis, and human–machine communication.
- Reinforcement Learning (RL): Used for autonomous systems, navigation, resource scheduling, and dynamic control.
- Digital Twin Modelling: Real-time AI models replicate physical assets for performance prediction and failure simulation.
- Intelligent Automation / Robotics: AI enhances path planning, manipulation, quality inspection, and collaborative robotics (cobots).

2.2. AI Applications Across Engineering Disciplines

2.2.1. Mechanical Engineering:

AI revolutionizes mechanical engineering (Fig. 4.) through intelligent design, manufacturing automation, and predictive analytics [6, 7].

Key Applications:

- Predictive Maintenance: Vibration, temperature, and acoustic data help predict equipment failures.
- Generative Design: AI-driven CAD tools optimize mechanical components.
- Robotics & Automation: Autonomous assembly, inspection, and material handling.
- Thermal Systems Modelling: AI predicts heat flow, HVAC performance, and energy consumption.
- Smart Manufacturing: Computer vision identifies defects; ML improves process efficiency.

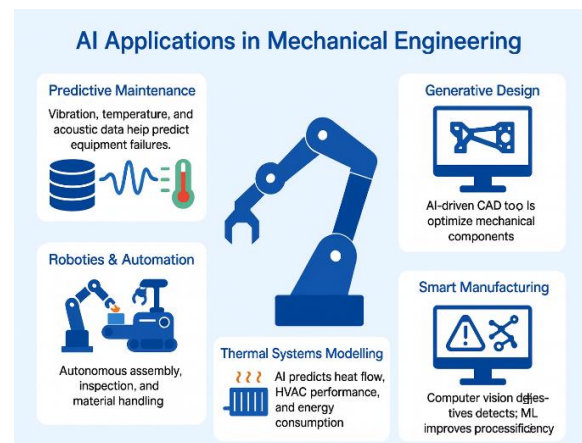


Figure 4 AI in Mechanical Engineering

2.2.2. Electrical Engineering

AI enhances power systems, signal processing, and energy management as shown in Fig. 5. [8].

Key Applications

- Smart Grids: Load forecasting, fault prediction, and intelligent energy routing.
- Power Electronics Control: AI stabilizes converters and inverters under varying load conditions.
- Embedded Systems: Edge-AI chips enable real-time decision-making.
- Renewable Energy Optimization: Solar/wind power prediction and grid integration. Figure 5 shows AI in Electrical Engineering

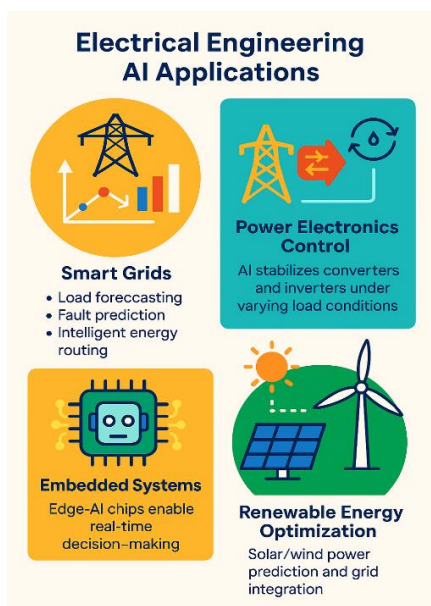


Figure 5 AI in Electrical Engineering

2.2.3. Electronics & Communication Engineering

Fig. 6. also shows AI in electronics engineering and is foundational to intelligent devices, 5G/6G networks, and embedded systems [9].

Key Applications

- AI-Driven Wireless Networks: Spectrum allocation using RL, interference minimization.
- VLSI Design Automation: Predictive layouts, defect minimization.
- IoT Systems: Embedded intelligence for sensors and devices.
- Signal Processing: Noise reduction, pattern recognition, and real-time filtering

Figure 6 shows AI in Electronics Engineering

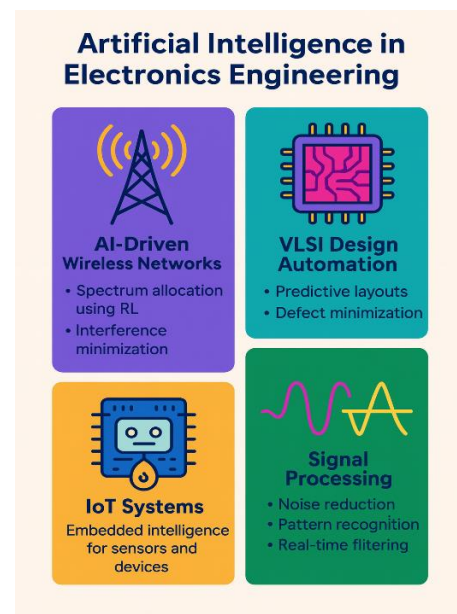


Figure 6 AI in Electronics Engineering

2.2.4. Computer Science & Information Technology

CS/IT acts as the backbone for AI deployment. Fig. 7 shows AI in Computer Engineering.

Key Applications

- Big Data Engineering: Handling massive datasets for analytics.
- Cloud & Edge AI: Distributed intelligence for real-time applications.
- Cybersecurity: AI-driven intrusion detection and threat prediction.
- Software Engineering: Automated testing, code generation, bug detection.

2.2.5. Civil & Structural Engineering

Fig. 8. shows AI in civil engineering. AI enables sustainable and safe infrastructure [10,11].

Key Applications

- Structural Health Monitoring: Computer vision detects cracks, deformation, corrosion.
- Smart Cities: Traffic prediction, environmental monitoring, resource optimization.
- Construction Automation: Drones, robotics, material planning using ML.
- Disaster Prediction: Earthquake detection (e.g., Prof. Numada Lab, Tokyo (Fig. 9.)) and flooding alerts using sensor data.



Figure 7 AI in Computer Engineering



Figure 8 AI in Civil Engineering



Figure 9 Prof. Numada Lab, Tokyo

2.2.6. Chemical & Process Engineering

AI supports chemical manufacturing, process control, and materials discovery as shown in Fig. 6.

Key Applications

- Process Optimization: AI tunes pressure, temperature, and reaction parameters.
- Catalyst Discovery: Deep learning models identify molecular structures.
- Plant Safety: Hazard prediction and risk analysis.
- Waste Management: AI-based filtration and treatment systems.

2.2.7. Aerospace Engineering

AI powers autonomy, precision, and enhanced safety (Fig. 10)

Key Applications

- Autonomous Flight: RL-based navigation and control.
- Fault Diagnosis: Real-time aircraft health monitoring.
- Aero-Design Optimization: CFD simulations accelerated by neural networks.
- Space Robotics: AI-driven rovers, robotic arms, and satellite operations.

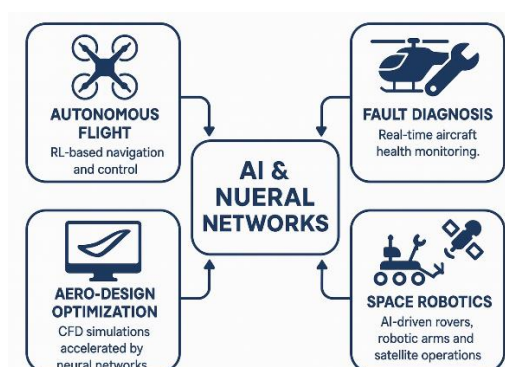


Figure 10 AI in Aerospace Engineering

2.2.8. Biomedical Engineering

AI is revolutionizing healthcare delivery and medical devices (Fig. 11) [12, 13].

Key Applications

- Medical Imaging: CNNs detect cancer, tumors, and lesions with high accuracy.
- Wearable Health Monitoring: Early detection of cardiac/anomaly events.
- Precision Medicine: Personalized treatment recommendations.
- AI-Assisted Surgery: Robotic surgery with real-time guidance.

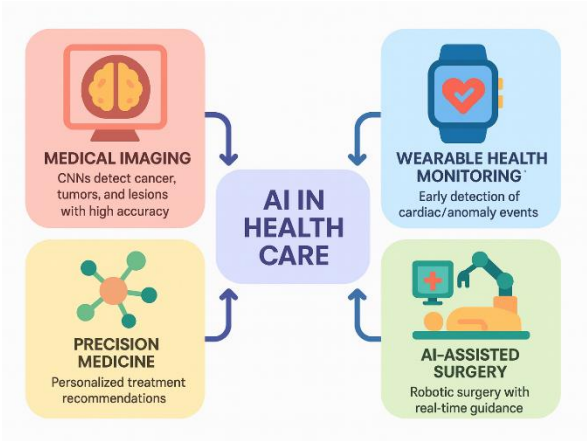


Figure 11 AI in Biomedical Engineering

2.2.9. Industrial & Manufacturing Engineering

Industry 4.0 relies heavily on AI for optimization and automation (Fig. 12) [14].

Key Applications

- Digital Factories: AI-integrated supply chains and automated logistics.

- Quality Control: Vision-based inspection in real time.
- Resource Scheduling: RL-based optimization of workforce and machinery.
- Demand Forecasting: Reducing inventory costs and maximizing output.



Figure 12 AI in Industrial and Manufacturing Engineering

Table 1 AI Techniques Across Engineering Domains

Engineering Domain	AI Techniques	Applications
Mechanical	Predictive Maintenance, CV	Fault detection, robotics
Electrical	Forecasting, RL	Smart grids, load balancing
Civil	CV, ML	Structural monitoring
Biomedical	DL, CV	Medical imaging

2.3. 2.3. Cross-Disciplinary Innovations

- Digital Twin Technology: Creates virtual replicas of machines, buildings, or processes for predictive and prescriptive insights.
- Industry 4.0 & Smart Manufacturing: Integrates AI, IoT, cloud computing, and robotics for autonomous production.
- Explainable AI (XAI): Ensures transparency in high-stakes engineering decisions.
- Sustainable & Green Engineering: AI minimizes energy consumption, emissions, and materials wastage.
- Autonomous Systems: Self-driving cars, drones, logistics robots, and automated inspection tools.

2.4. Challenges and Ethical Considerations

- Data Quality and Availability: Engineering systems often generate incomplete, noisy, or imbalanced data.
- Interoperability Issues: Legacy machines struggle to integrate with modern AI solutions.
- Ethical and Legal Concerns
 - Accountability of autonomous systems
 - Privacy in sensor-based monitoring
 - Algorithmic bias in critical decision systems
- Skill Gap: Strong need for interdisciplinary engineers proficient in both domain knowledge and AI.

AI in Multidisciplinary Engineering

- Computational Constraints: High-performance computing is required for training advanced AI models.

3. Results and Discussions

AI integration across engineering disciplines marks a paradigm shift toward:

- Data-driven engineering
- Autonomous and self-optimizing systems
- Reduced reliance on physical experiments
- Rapid prototyping and design validation
- Enhanced safety, sustainability, and efficiency

AI's cross-disciplinary nature fosters collaboration across domains, unlocking innovative solutions previously impossible with traditional engineering approaches.

Future Scope

- Universal Interdisciplinary AI Platforms: Common AI frameworks for mechanical, civil, biomedical, and chemical engineering.
- Autonomous Laboratories: Fully automated experimental systems for materials, chemistry, and biotech.
- AI-Augmented Human Expertise: Engineers will work alongside AI assistants for rapid decision-making.
- Edge AI for Real-Time Engineering: Low-latency intelligence embedded directly into machines and devices.
- Sustainability-Centric AI: Models designed explicitly for carbon reduction, energy efficiency, and environmental preservation.

Conclusions

AI has become a core pillar of modern engineering across all major disciplines. Its ability to analyse data, learn patterns, automate tasks, and make intelligent decisions enables unprecedented advancements in design, manufacturing, healthcare, infrastructure, aerospace, and industrial systems. While challenges remain regarding data quality, ethics, and interoperability, the future of engineering is undeniably AI-driven. This review demonstrates that AI is not merely an added capability—it is a foundational enabler that defines the next generation of global engineering innovation.

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